

# NGC 5506 Unmasked as a Narrow Line Seyfert 1:

## A Direct View of the Broad Line Region using Near-IR Spectroscopy\*

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**Abstract.** This letter presents incontrovertible evidence that NGC 5506 is a Narrow Line Seyfert 1 (NLSy1). Our new 0.9–1.4  $\mu\text{m}$  spectrum of its nucleus clearly shows the permitted O I  $\lambda$ 1.287  $\mu\text{m}$  line (with full width at half maximum  $< 2000 \text{ km s}^{-1}$ ) and the ‘1 micron Fe II lines’. These lines can only originate in the optically-thick broad line region (BLR) and, among Seyfert nuclei the latter series of lines are seen only in NLSy1s. The obscuration to the BLR, derived from a rough estimate of the O I  $\lambda$ 1.287  $\mu\text{m}$ /O I  $\lambda$ 8446 ratio and from the reddening of the near-IR Paschen lines, is  $A_V > 5$ . Together, these results make NGC 5506 the first identified case of an optically-obscured NLSy1. This new classification helps explain its radio to X-ray properties, which until now were considered highly anomalous. However, interesting new concerns are raised: e.g., NGC 5506 is unusual in hosting both a ‘type 1’ AGN and a nuclear water vapor megamaser. As the brightest known NLSy1, NGC 5506 is highly suitable for study at wavebands less affected by obscuration.

**Key words.** line: formation — line: identification — galaxies: active — galaxies: individual (NGC 5506) — galaxies: Seyfert — infrared - galaxies

### 1. Introduction

The Seyfert nucleus of NGC 5506 has resisted a clear type classification within Seyfert galaxies, and there is a long standing debate on whether it is an intermediate type 1 (broad H $\alpha$  directly visible) or type 2 (broad H $\alpha$  not directly visible) Seyfert. The presence of ‘broad’ Pa $\beta$  has been reported by Blanco, Ward, & Wright (1990), Rix et al. (1990), and Ruiz, Rieke, & Schmidt (1994), but Goodrich, Veilleux, & Hill (1994) found that the ‘narrow’ line emission profiles become broader at longer wavelengths and suggested that the ‘broad’ Pa $\beta$  was the strong, highly reddened wings of this profile. Based on data available at that time Goodrich, Veilleux, & Hill (1994) interpreted the broadening of emission lines with wavelength as due to obscuration of the inner parts of the narrow line region. Morris & Ward (1985) reported a marginal detection of O I  $\lambda$ 8446, characteristic of Seyfert 1s, and suggested the presence of high-density optically thick gas. At odds

with other type 2 objects, the nucleus of NGC 5506 is dominated by a bright compact core at all near-IR wavelengths and 60% of the J-band (1.25  $\mu\text{m}$ ) flux in its central few arcsec is non-stellar in origin (Oliva et al., 1999; Alonso-Herrero et al., 2001). In the hard X-ray it is one of the most luminous and brightest Seyferts in the local universe ( $?, L_{2-10\text{keV}} \sim 10^{43}; \text{mus82}$  and its obscuring column ( $?, N_{\text{H}} = 3.4 \times 10^{22} \text{ cm}^{-2}; \text{baset99}$  is intermediate between typical values for Seyfert 1s and 2s. Nuclear water vapor masers, a property highly correlated with a type 2 spectral classification (Braatz, Wilson, & Henkel, 1996), have been detected towards its nucleus (Braatz, Wilson, & Henkel, 1994).

The host galaxy causes additional complications. The galaxy disk is close to edge on ( $i = 70^\circ$ ), and dust in the galaxy disk is responsible for some or all of the nuclear reddening (Veilleux, Goodrich, & Hill, 1997; Imanishi, 2000). NGC 5506 is therefore variously treated as a type 1.9 or type 2 Seyfert in the literature and in either case is usually an outlier among the members of its class.

In this letter we report on near-IR spectroscopy of NGC 5506, which unequivocally identifies it as a Narrow Line Seyfert 1 (NLSy1). In a NLSy1 the broad line region (BLR) is directly visible with the BLR emission lines having widths typically  $\leq 2000 \text{ km s}^{-1}$ , significantly narrower

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\* Based on observations made with the Italian Telescopio Nazionale Galileo (TNG) operated on the island of La Palma by the Centro Galileo Galilei of the INAF (Istituto Nazionale di Astrofisica) at the Spanish Observatorio del Roque de los Muchachos of the Instituto de Astrofisica de Canarias

than those in classical Seyfert 1s. NLSy1s show several anomalous properties, most notably in the X-ray (? for a nice overview of these see)]veret01 and explanations for these include accretion rates close to the Eddington rate (implying lower black hole masses than other Seyferts) or a view to the AGN along its axis.

## 2. Observations and Data Reduction

Data were obtained on 17 January 2001 using NICS, the near-IR imager and spectrograph on the 3.5 meter Telescopio Nazionale Galileo (TNG). We used the low-resolution IJ grism and a slit width of  $0''.75$ , yielding a dispersion of  $5.7\text{\AA}/\text{pix}$  (resolution  $16\text{\AA}$ ) over the wavelength range  $0.89\text{--}1.46\text{ }\mu\text{m}$ , and a scale of  $0.25''/\text{pixel}$  along the slit. The slit was centered on the near-IR peak and rotated to position angle  $140^\circ$  North of East. Total integration time on source was 20 min, consisting of four 5 min exposures in the standard ‘ABBA’ position raster. The observations were immediately followed by observations of the star HIP 69160 using the same instrument setup. The sky was not photometric and the seeing about  $1''$ .

Data were reduced using standard tasks within IRAF. The spectrum of HIP 69160 (stellar type G5V) was corrected for its intrinsic spectral shape and then used to correct the atmospheric absorption lines in the spectrum of NGC 5506. Absolute flux calibration was derived by previous observations of photometric standard stars and should be accurate to about 30%. Finally, the spectrum was Doppler corrected using a recessional velocity of  $1815\text{ km s}^{-1}$  as derived from HI observations (de Vaucouleurs et al., 1991). The final resolution was  $\sim 16\text{ }\text{\AA}$  over the full wavelength range.

## 3. Results

The final nuclear spectrum of NGC 5506 is shown in Fig. 1 with emission-line fluxes listed in Table 1. The main result of this paper is based on our clear detection of the *permitted* O I  $\lambda 1.1287\text{ }\mu\text{m}$  line and the detection of the ‘1 micron Fe II lines’. The O I  $\lambda 1.1287\text{ }\mu\text{m}$  line, along with O I  $\lambda 8446$ , is produced by Ly $\beta$  pumping in a Bowen fluorescence mechanism (Grandi, 1980). The latter line was tentatively detected by Morris & Ward (1985). Both the above O I lines are produced only by high density optically-thick gas and are usually seen in Seyfert 1s but never in Seyfert 2s (? , e.g.)]morwar85.

The ‘1 micron Fe II lines’ at  $\lambda 0.9997\text{ }\mu\text{m}$ ,  $\lambda 1.0501\text{ }\mu\text{m}$ ,  $\lambda 1.0863\text{ }\mu\text{m}$ , and  $\lambda 1.1126\text{ }\mu\text{m}$  are posited to originate in BLR clouds. Theoretically, such Fe II lines and their related optical and UV counterparts are expected in only type 1 objects and to be strongest in NLSy1s (? , e.g.)]coljol00. Observationally, these lines have been previously detected in only six extragalactic objects, all NLSy1s: I Zwicky 1 (Rudy et al., 2000), Mrk 478 (Rudy et al., 2001), 1H 1934, Ark 564, Mrk 335, and Mrk 1044 (Rodríguez-Ardila et al., 2002). Detailed discussions on the origin of the lines can be found in these papers.

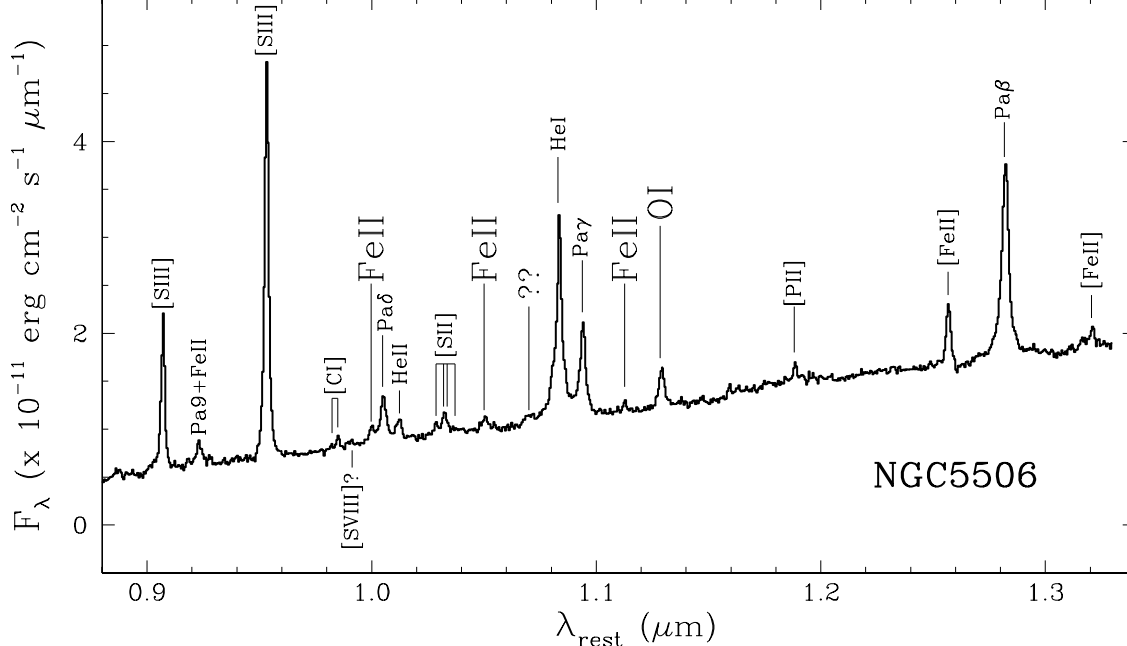
Table 1. Line fluxes in NGC 5506

Line	Obs. flux	Eg. Dered.	$A_\lambda/A_V$	Comments
(1)	(2)	(3)	(4)	(5)
O I 0.8447	<6:	<27:	0.55	Morris & Ward
[S III] 0.9069	39	105	0.48	
Pa $\gamma$ +Fe II 0.923	9	23	0.47	blend
[S III] 0.9531	125	280	0.44	includes Pa $\delta$
[C I] 0.9850	3	6	0.42	
[S VIII] 0.9913	1?	2?	0.41	marginal det.
Fe II 0.9997	6	12	0.41	
Pa $\delta$ 1.0049	18	34	0.40	case-B = 34
He II 1.0123	8	15	0.40	
[S II] 1.033	12	21	0.38	
Fe II 1.0501	6	10	0.37	
?? 1.070	5	8	0.36	seen in NLSy1s
He I 1.083	74	110	0.35	
Fe II 1.0863	8?	12	0.35	blend with He I
Pa $\gamma$ 1.0938	36	54	0.35	case-B = 55
Fe II 1.1126	1:	1:	0.35	marginal det.
O I 1.1287	14	19	0.33	
[P II] 1.1882	4	5	0.30	
[Fe II] 1.2567	20	21	0.27	
Pa $\beta$ 1.2818	100	100	0.26	case-B = 100
[Fe II] 1.3206	6	...	0.25	
Pa $\beta$ flux	84	280		$10^{-15}\text{ erg/cm}^2/\text{s}$

Column (2) lists the flux measured in our  $0''.75 \times 1''.25$  nuclear aperture, relative to a Pa $\beta$  flux of 100, except for the O I 0.8446 line which was measured in a  $1''.5 \times 10''$  nuclear aperture (Morris & Ward 1985). Entries marked with a “?” or “:” are uncertain. The absolute flux of the Pa $\beta$  line (accurate to  $\pm 30\%$ ) in units of  $10^{-15}\text{ erg cm}^{-2}\text{ s}^{-1}$  is listed in the last line of the table. Column (3) lists the measured flux after dereddening by an illustrative extinction of  $A_V=5$  (see text), relative to a (dereddened) Pa $\beta$  flux of 100. Column (4) lists the  $A_\lambda/A_V$  values, derived from the standard extinction curve, used to calculate column (3). The expected relative fluxes for the first three lines in the Paschen series, assuming Case B recombination, are listed in column (5).

Two of the four lines are clearly detected in our spectrum (Fig. 1). The third, Fe II  $\lambda 1.0863\text{ }\mu\text{m}$ , is blended with the very strong He I  $\lambda 1.083\text{ }\mu\text{m}$  line and the fourth, Fe II  $\lambda 1.1126\text{ }\mu\text{m}$ , is only marginally detected as it is in a region of atmospheric absorption. A broad emission feature at  $1.07\text{ }\mu\text{m}$ , just blue-ward of He I  $\lambda 1.0630\text{ }\mu\text{m}$ , is also present. This feature is also seen in all six NLSy1s listed above but has not been identified.

The Pa $\beta$  line has a broad pedestal (Fig. 2) and is best fit (after deconvolving the instrumental resolution) by two Gaussians with full width half maximum (FWHM)  $500\text{ km s}^{-1}$  and  $1800\text{ km s}^{-1}$ ; the broader line contains  $\sim 53\%$  of the flux. The similarity between the O I (BLR only) and Pa $\beta$  (BLR+NLR) line profiles (Fig. 2) suggests that this double Gaussian fit does not perfectly separate emission from the NLR and BLR, respectively. The [Fe II] line profile is only slightly resolved at our instrument resolution, but nevertheless appears different from that of Pa $\beta$



**Fig. 1.** NICS/TNG spectrum of NGC 5506 in an  $0''.75 \times 1''.25$  nuclear aperture. Most detected lines are labelled.

(Fig. 2). These results are different from those of Veilleux, Goodrich, & Hill (1997) who found that both Pa $\beta$  and [Fe II] have similar profiles, with their wings well fitted with a Lorentzian rather than a broad Gaussian component. We were unable to satisfactorily fit our line profiles following the functional form of their fit. It is likely that the line profiles are affected by significant variability. Given the FWHM of the broad components of Br $\gamma$  ( $1550 \pm 100$  km s $^{-1}$  from data taken by R. Maiolino in 1995) and Br $\alpha$  ( $?, 1200 \pm 100$  km s $^{-1}$ ;)]lutet02, it appears that the width of the broad component of the near-IR permitted lines does not increase with wavelength, suggesting that the O I  $\lambda 1.1287 \mu\text{m}$  and Pa $\beta$  profiles trace the bulk of the BLR rather than only the outer less obscured part. If this is true, the profile of the H $\alpha$  emission from the BLR should be similar to that of O I (Grandi, 1980), though the latter line may be narrower in NLSy1s (Rodríguez-Ardila et al., 2002).

The observed Pa $\beta$ , Pa $\gamma$ , and Pa $\delta$  fluxes are consistent with those expected when viewing case-B recombination through an extinction of  $A_V = 5$  (cols. 3 to 5 of Table 1). That is, for the case-B assumption and an error of  $\sim 13\%$  in the Pa $\beta$ /Pa $\delta$  ratio, our data are consistent with extinction  $A_V = 5 \pm 1$  mag towards the Paschen lines. The true extinction to the broad line region is expected to be higher than this illustrative value as our aperture ( $\sim 100$  pc at the distance of NGC 5506) includes emission from the presumably less-extincted narrow line region.

A more direct measure of the extinction to the BLR comes from the O I  $\lambda 1.1287 \mu\text{m}$ /O I  $\lambda 8446$  ratio, which is reddening sensitive (intrinsic value = 1.34). In all the published spectra of NLSy1 the observations are compatible with zero relative extinction between the two lines (Rudy et al., 2000, 2001; Rodríguez-Ardila et al., 2002).

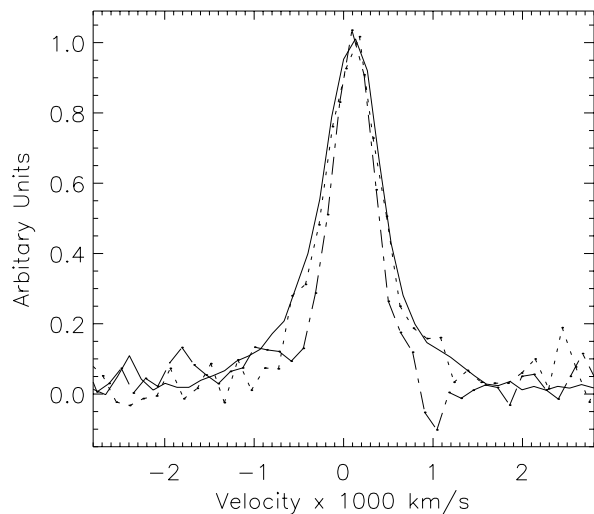
The only available data on O I  $\lambda 8446$  in NGC 5506 is the spectrum of Morris & Ward (1985, 1988) where this line is only marginally detected. Their spectrum is flux calibrated and partially overlaps with ours. From a comparison between both absolute O I fluxes and O I fluxes scaled to the [S III] lines<sup>1</sup> we find a lower limit of 2 for the O I  $\lambda 1.1287 \mu\text{m}$ /O I  $\lambda 8446$  flux ratio, which translates into a relative reddening  $A_{0.8446} - A_{1.1287} > 1$ . Adopting a standard reddening curve, this gives  $A_V > 5$ . This result is uncertain due to potential variability, different aperture sizes, and non-photometric conditions. Simultaneous observations of both O I lines are therefore highly desirable.

#### 4. Discussion

The currently used classification for NLSy1s (?, from)]pog00 is: 1. narrow permitted lines only slightly broader than forbidden lines; 2.  $\text{FWHM}(\text{H}\beta) < 2000$  km s $^{-1}$ ; 3.  $[\text{O III}]/\text{H}\beta < 3$ , but exceptions allowed if there is also strong [Fe VII] and [Fe X] present, unlike what is seen in Seyfert 2s.

We have shown that the BLR emission is detected in the near-IR and that the O I and Pa $\beta$  line profiles likely sample the bulk of the BLR. Thus, with O I (from the BLR only) and Pa $\beta$  (from BLR and NLR) line widths  $< 2000$  km s $^{-1}$ , NGC 5506 directly satisfies the first two conditions. The observed [O III]/H $\beta$  ratio is 7.5 at the nu-

<sup>1</sup> A direct comparison of absolute fluxes gives O I  $\lambda 1.1287 \mu\text{m}$ /O I  $\lambda 8446 \geq 2$  (higher if we consider that our narrower slit captured less light from the seeing-limited BLR). A comparison of O I fluxes scaled to the [S III] lines (after correcting for differences in the apertures) gives O I  $\lambda 1.1287 \mu\text{m}$ /O I  $\lambda 8446 \sim 4$  (higher if the aperture corrections are not used).



**Fig. 2.** Comparison of the velocity profiles of  $\text{Pa}\beta$  (solid line),  $\text{O I } \lambda 1.1287 \mu\text{m}$  (dotted line), and  $[\text{Fe II}] \lambda 1.2567 \mu\text{m}$  (dash-dot line). The instrumental resolution ( $16 \text{ \AA}$  at all three lines) has not been subtracted out.

cleus and this ratio remains high over most of the extended emission-line region (Wilson, Baldwin, & Ulvestad, 1985). If the BLR is highly extinguished as our results suggest then the BLR contribution to the  $\text{H}\beta$  flux would likely change the unextinguished nuclear  $[\text{O III}]/\text{H}\beta$  ratio to  $< 3$ , bringing NGC 5506 into agreement with the third condition for classification as a NLSy1. A high extinction to the BLR would also explain the lack of strong optical Fe II lines as usually seen in NLSy1s. NGC 5506 shares other properties unique to NLSy1s including the presence of the ‘1 micron Fe II lines’ as shown here, a high X-ray luminosity, steep X-ray slope, and fast X-ray variability (Lamer, Uttley, & McHardy, 2000). NGC 5506 is now the brightest known NLSy1 and therefore most suited for studies in wavebands not affected by obscuration. An important issue raised is whether several other X-ray bright and highly variable ‘type 2’ Seyferts are, like NGC 5506, partially obscured NLSy1s.

Several properties of NGC 5506 still remain, or now become, anomalous. Mathur, Kuraszkiewicz, & Czerny (2001) find evidence that NLSy1s have preferentially lower black hole masses and are accreting at high values of  $L/L_{\text{Eddington}}$ . However, the high central velocity dispersion in NGC 5506 ( $\sim 180 \text{ km s}^{-1}$ ; Joliet 99 though somewhat uncertain, implies a relatively high black hole mass among Seyferts, if the scaling between velocity dispersion and black hole mass is valid among Seyferts (Wandel, 2002). NGC 5506 is also unusual in being a type 1 AGN with a nuclear megamaser. Both the X-ray column (Risaliti et al., 2002) and narrow maser lines (Braatz, Wilson, & Henkel, 1996) are variable, and it may be that the latter are produced during periods when the column to nucleus is temporarily higher.

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